Beam Based Alignment At RHIC

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(and probably Al Marusic…)

RHIC Retreat

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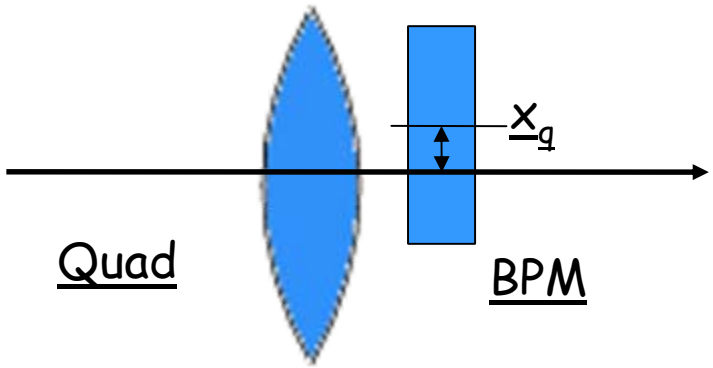
Motivation

Goal: Compensate for quadrupole misalignments/BPM offsets by calibrating BPMs to read zero (via the use of electronic offsets) when beam is steered through quadrupole center.

- Improve orbit through IRs
  - Luminosity development
  - Background minimization
  - Maximize aperture
- Polarization preservation
- Study long term reproducibility of calculated electronic offsets

Method

- Measure beam offset from quad center



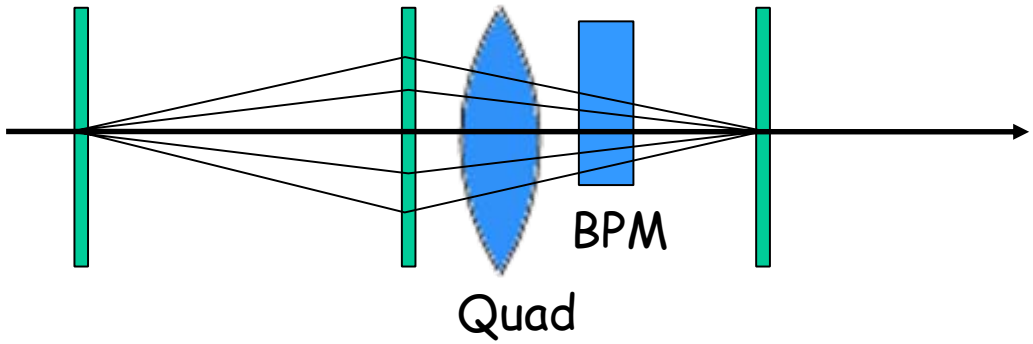
Dipole kick from the quad misalignment can be used to calculate the offset in position

$$x_q = \frac{\theta}{\Delta k}\left(1 + \frac{k\beta}{2\tan(\pi Q)}\right)$$

N.B. Additional dispersive term is required if dispersion at quad is large.

The Method, Improved

- Vary strength of quad at different bump settings across the quad, minimizing the dipole kick as a function of BPM reading:



- Accounts for closed orbit distortion from dipole kick
- Pros/cons
  - •Nullify bump leakage by taking a baseline at every measurement.
  - •Accurate with many (>5) bump settings.
  - •SLOW.

Experimental Time

- Three runs, all dedicated APEX time
  - Motivated by question of orbit changes in IR6 and IR8.
  - Test installation of survey offset in IRs
- Setbacks, improvements, and improvisations:
  - First run was essentially a loss due to data collection failure.
  - Improved scripts after first run to use DoLiveStrengths interface in WfgMan (also used for ORM)
    - Faster and less intrusive than previous method (.tcl'ing CDEV)
    - Reverted with a ramp activate (easy return to APEX)
  - Discovered some interesting things about the orbit

Experimental Runs

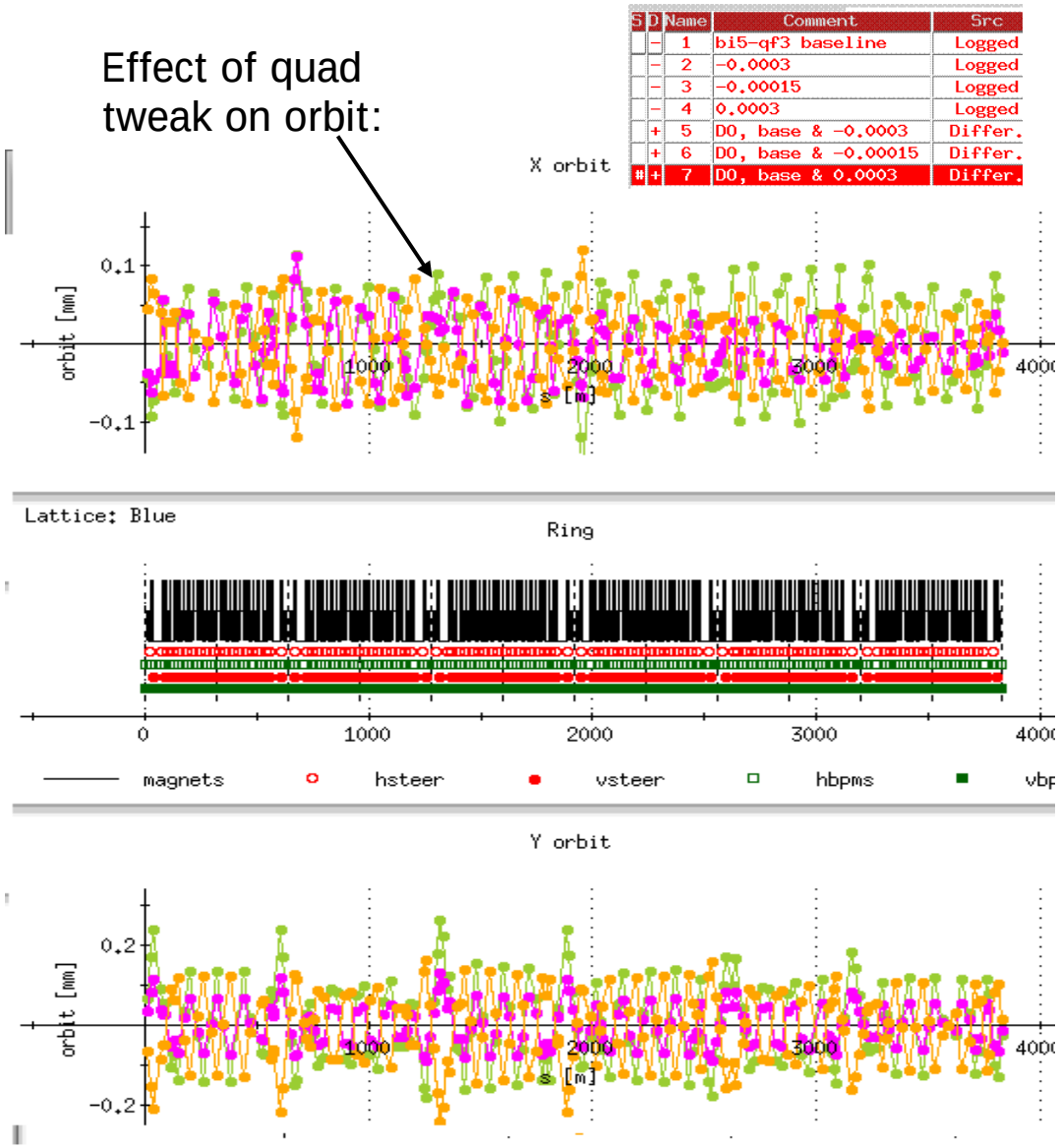
Quad Optics IR 6
May 3 – Fill 7809

Quad	k[m^{-2}]	ßx[m]	ßy[m]
bo6-qd1	-0.08092	70.640	83.978
bo6-qd3	-0.11459	52.556	159.976
bi5-qf3	0.11446	135.445	65.159
bi5-qf1	0.08115	73.971	86.594
yi6-qf1	0.08115	72.661	85.830
yi6-qf3	0.11476	133.153	64.460
yo5-qd3	-0.11448	52.487	157.468
yo5-qd1	-0.08092	70.788	82.726

Machine optics acquired from online model at run time.

Δk ranged +/- 0.0003 m^{-2}
Bumps ranged +/- 5 mm
Baseline orbits taken for every measurement.

Effect of quad tweak on orbit:



Results

April 25th (fill 7783)

```
bi5-qf1
 h =>  0.016 +/-  0.288
 v => -3.307 +/-  0.075
bi5-qf3
 h => -1.008 +/-  0.200
 v =>  0.748 +/-  0.005
bo6-qd1
 h =>  0.442 +/-  0.250
 v => -1.228 +/-  0.119
bo6-qd3
 h => -0.404 +/-  0.030
 v => -0.318 +/-  0.258


yo5-qd3
 h => -1.157 +/-  0.529
 v => -0.580 +/-  0.103
yo5-qd1
 h => -2.394 +/-  0.843
 v =>  0.213 +/-  0.202
yi6-qf1
 h =>  1.425 +/-  0.076
 v => -0.522 +/-  0.114
yi6-qf3
 h => -1.070 +/-  0.166
 v => -0.441 +/-  0.260
```

May 3rd (fill 7809)

```
bi5-qf1
 h => -0.369 +/-  0.105
 v => -2.688 +/-  0.322
bi5-qf3
 h => -0.936 +/-  0.159
 v =>  0.825 +/-  0.084
bo6-qd1
 h =>  0.576 +/-  0.077
 v => -1.838 +/-  0.206
bo6-qd3
 h =>  0.157 +/-  0.606
 v =>  0.052 +/-  0.296


yo5-qd3
 h => -1.226 +/-  0.392
 v => -0.266 +/-  0.037
yo5-qd1
 h => -5.115 +/-  0.673
 v =>  0.566 +/-  0.034
yi6-qf1
 h =>  0.065 +/-  0.449
 v =>  0.171 +/-  0.499
```

*all results in mm

Offset Installation

	Without offset*	With offset*
April 25th 7783	bi5-qf1 h => 0.016 +/- 0.288 v => -3.307 +/- 0.075 bo6-qd3 h => -0.404 +/- 0.030 v => -0.318 +/- 0.258	bi5-qf1 h => -1.131 +/- 0.500 v => -2.842 +/- 0.797 bo6-qd3 h => -0.818 +/- 0.817 v => 0.333 +/- 0.441
May 3rd 7809	bi5-qf1 h => -0.369 +/- 0.105 v => -2.688 +/- 0.322 bo6-qd3 h => 0.157 +/- 0.606 v => 0.052 +/- 0.296	bi5-qf1 h => -1.307 +/- 0.081 v => -2.853 +/- 0.044 bo6-qd3 h => 0.027 +/- 0.288 v => 0.085 +/- 0.044

Installed survey offsets (in um)

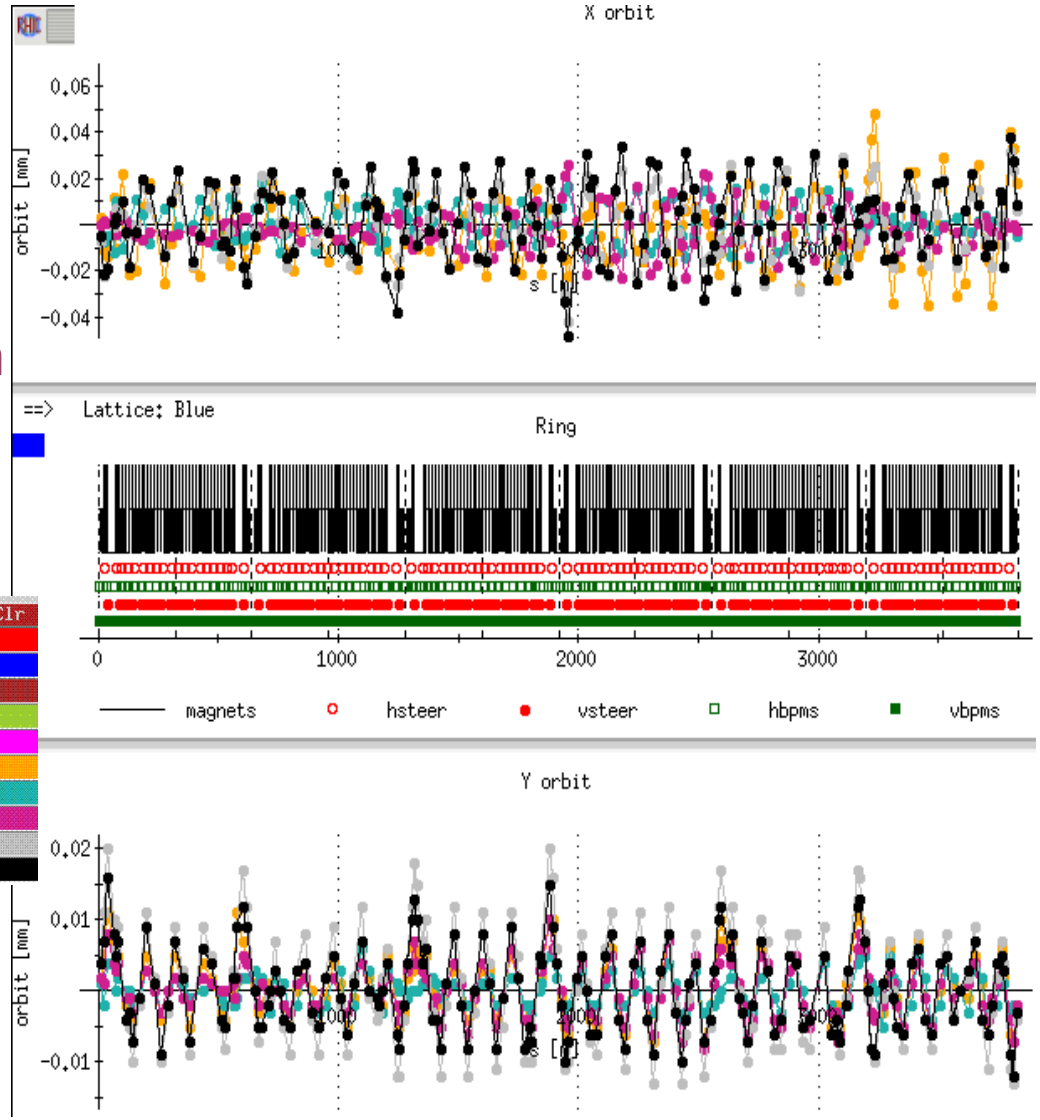
bi5-bh1 -587 bo6-bh3 185

*All values in mm

Error Sources

- Orbit Drift
  - Orbits taken over ten seconds while idle at injection.
  - Pronounced variation in both planes on the time scale of the measurement.

S	D	Name	Comment	Src	Clr
	–	2	No comment	Logged	
	–	3	No comment	Logged	
	–	4	No comment	Logged	
	–	5	No comment	Logged	
	–	6	No comment	Logged	
	+	7	Difference orbit: We	Differ.	
	+	8	Difference orbit: We	Differ.	
	+	9	Difference orbit: We	Differ.	
	+	10	Difference orbit: We	Differ.	
#	+	1	Difference orbit: We	Differ.	

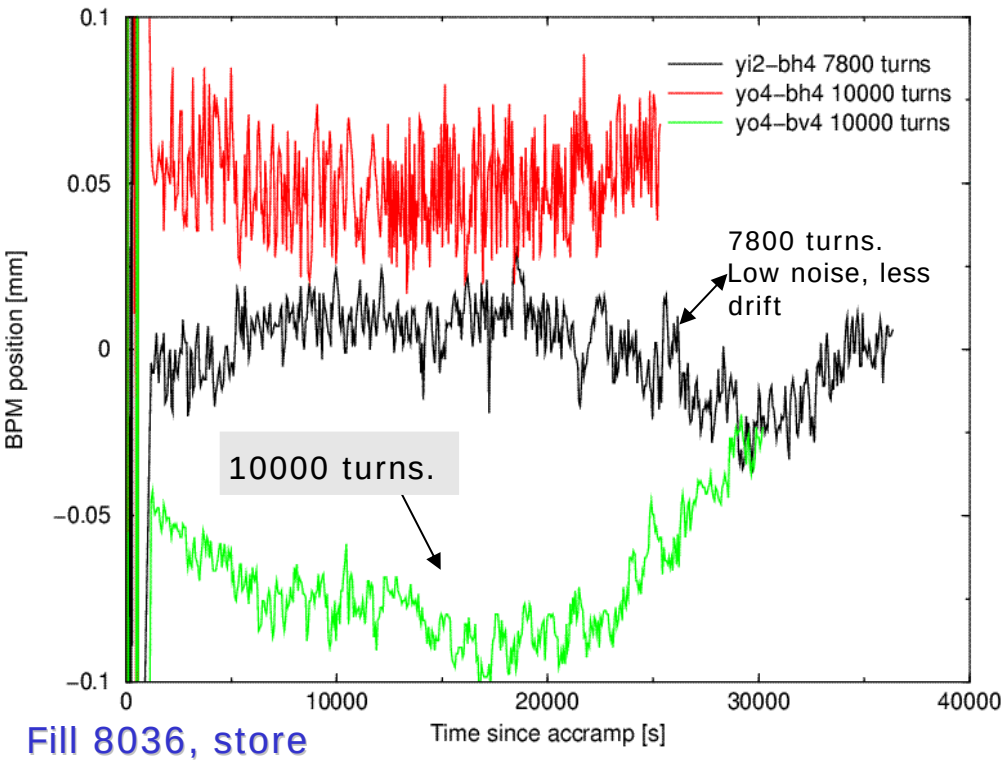


Orbits taken between 20:10:32 – 20:10:41, Fill 7809

Error Sources

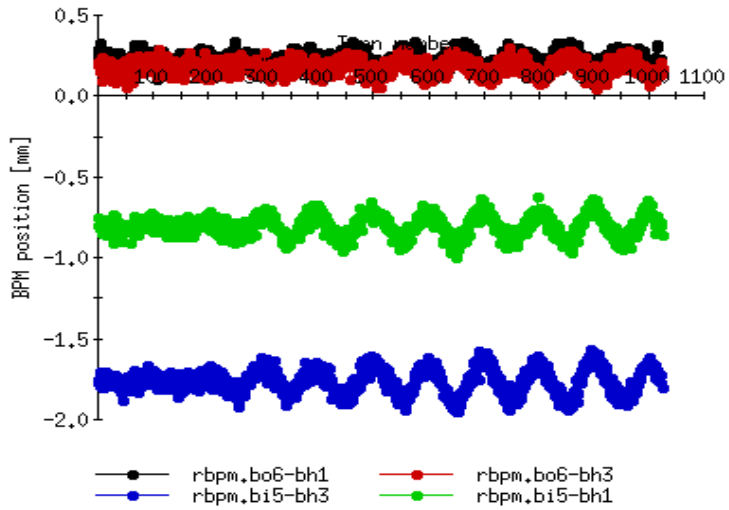
o 10 Hz noise:

- Currently use 10000 orbits to create an average
  - ~1.3 10Hz periods
- Change orbit averaging to some multiple of the 10Hz

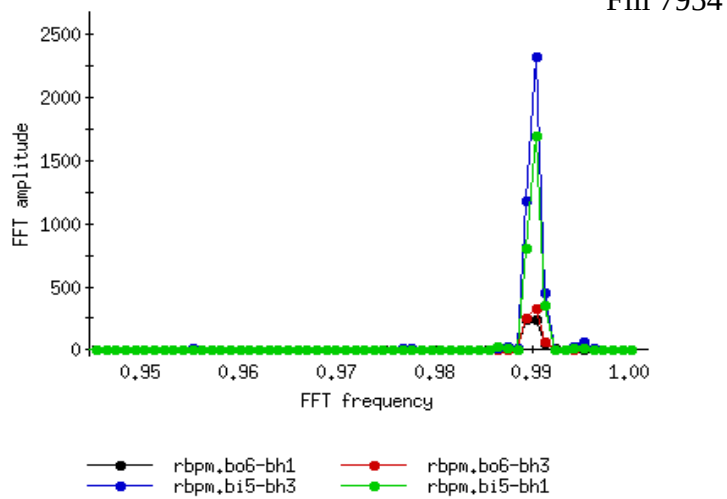


Fill 8036, store

At Injection, x1 gain
BPM sampling every 78 turns.



Fill 7954



New Method

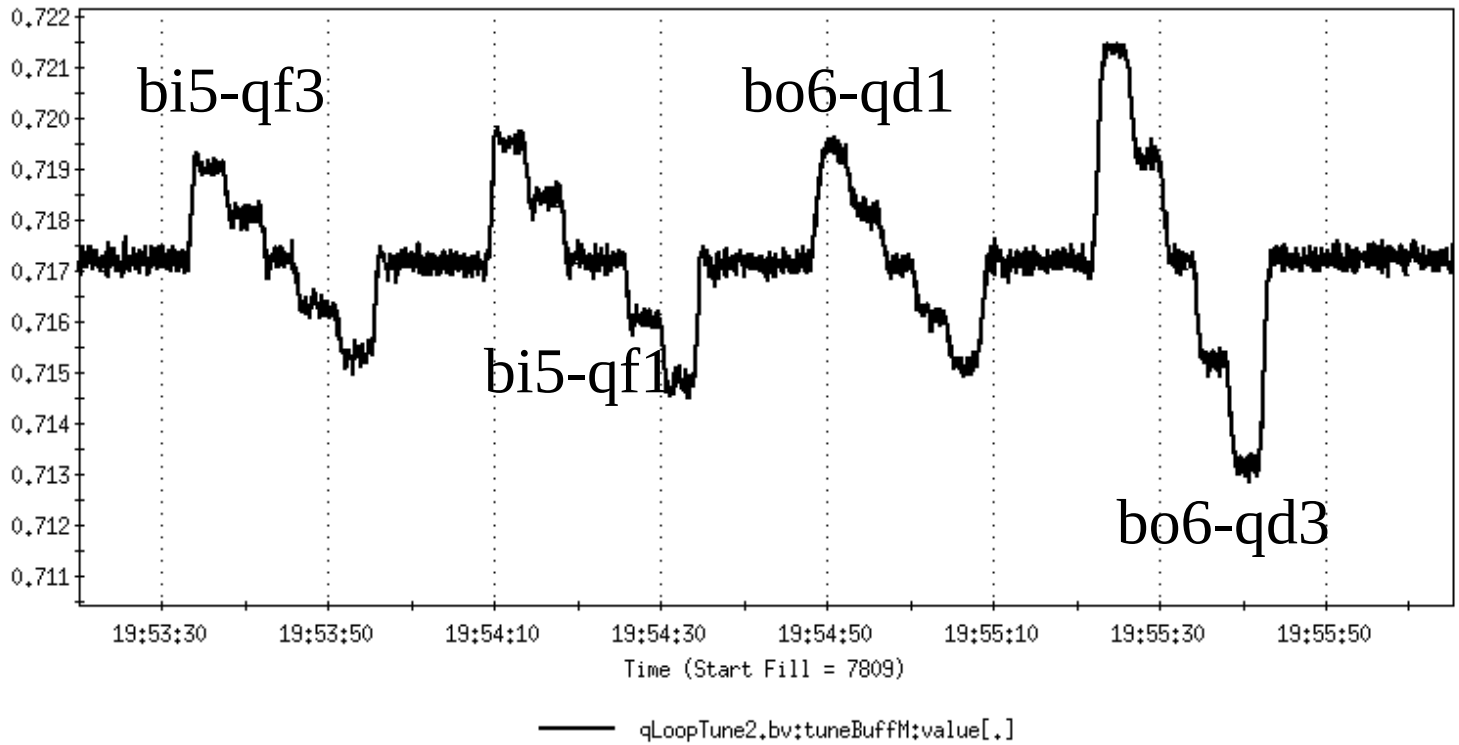
- Improve the method again:
  - Modulate quad at 1Hz, bump at 2/3 Hz
  - Use RHIC Turn by Turn buffering down-sampled to 1/78.
    - Sampling extremely good at injection.
    - No visible 1 Hz component (or very small) at injection
  - Fit 1 Hz component to bump strength, and minimize
- Potentially very fast, online method of returning result
- Hopefully easy to implement
  - Modulation available in IR quads and correctors
  - Several capabilities available
    - Modulate in physics or engineering units
    - Correctors can be modulated using sine or sawtooth waves
- Less intrusive than other methods
  - Undone with a ramp activate – allows easy return to program

2007 Goals

- New Method
  - Test out during APEX time
    - 1-2 sessions
      - Proof of principle
      - Operational program bench test
  - Operational release of a program that will perform BBA measurements
    - Calculation of offset data (frequency? TBD)
    - Utilization of failure time ("with beam" failures?)
- Ready with old method if new method fails
  - Take more data across a greater bump range
  - Will need dedicated time (APEX or other) to make fully operational
  - Requires code overhaul – in progress
- Fixing error sources
  - Additional orbit averaging (7800 or 15600 turns vs. 10000).
  - BBA with 10 Hz correction

More 2007 Plans

- Use BBQ to take absolute beta function measurements at the quad:

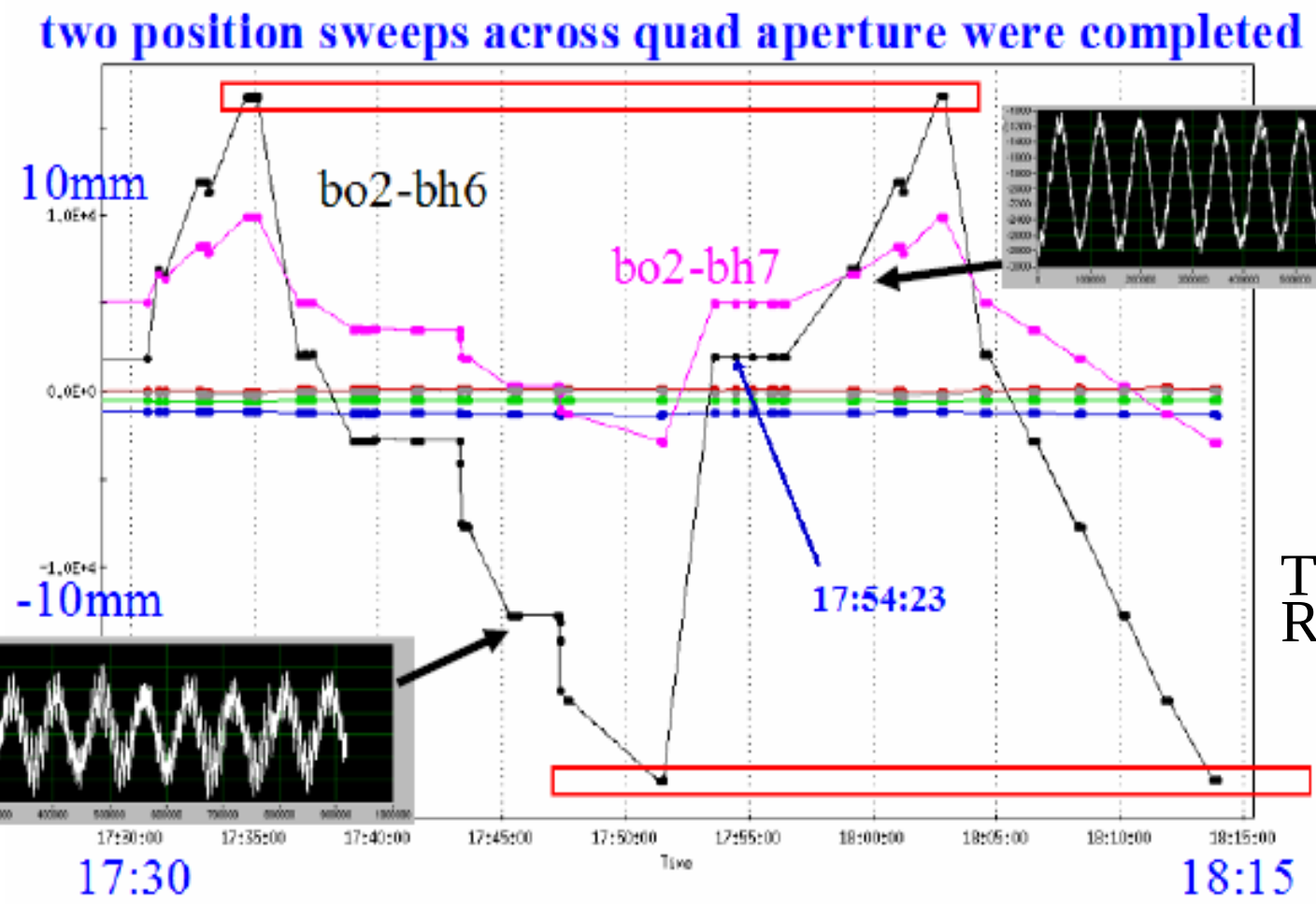


Fill 7809

Summary

- Recap
  - 2 reasonable data runs.
    - Code advances.
    - Offsets found to vary a fair bit, but only two data sets.
    - Conclude method isn't the most robust, and slow to boot.
  - Identified error sources
    - Orbit averaging and drift
    - 10 Hz noise
- Development of new method
  - Improve both strength and speed of obtaining results.
  - Hopefully easy to implement, contingency plan ready if not.

E-Cooling BBA 2005



T. Satogata, Retreat 2005

- Move beam position, modulate quadrupole at 1 Hz and measure million-turn BPM response at 1 Hz

Thin-lens correction and IR quad parameters

- Hoffstaetter/Willeke [PRST:AB 5, 102801 (2002)] found the scaling error in thin-lens approximation for IR quadrupoles:

$$\sigma^{-} = \frac{l\sqrt{k} - \sin(l\sqrt{k})}{2l\sqrt{k}}$$

Name	Length [m]	Strength k [m^{-2}]	β_x [m]	β_y [m]	Scaling error σ^{-}
bi5-qf3	3.39	0.1148	114.47	62.06	0.103
bi5-qf1	1.44	0.0809	76.10	82.83	0.014
bo6-qd1	1.44	-0.0809	83.00	78.36	0.014
bo6-qd3	3.39	-0.1148	61.87	148.49	0.103
bo11-qd1	1.44	-0.0809	80.91	76.45	0.014
bi12-qf1	1.44	0.0809	76.95	80.95	0.014

- Typical RHIC IR quadrupole parameters in β*=10m injection optics

T. Satogata